Laws of mesostrain distribution in aluminum strip rolling

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Laws of Mesostrain Distribution in Aluminum Strip Rolling

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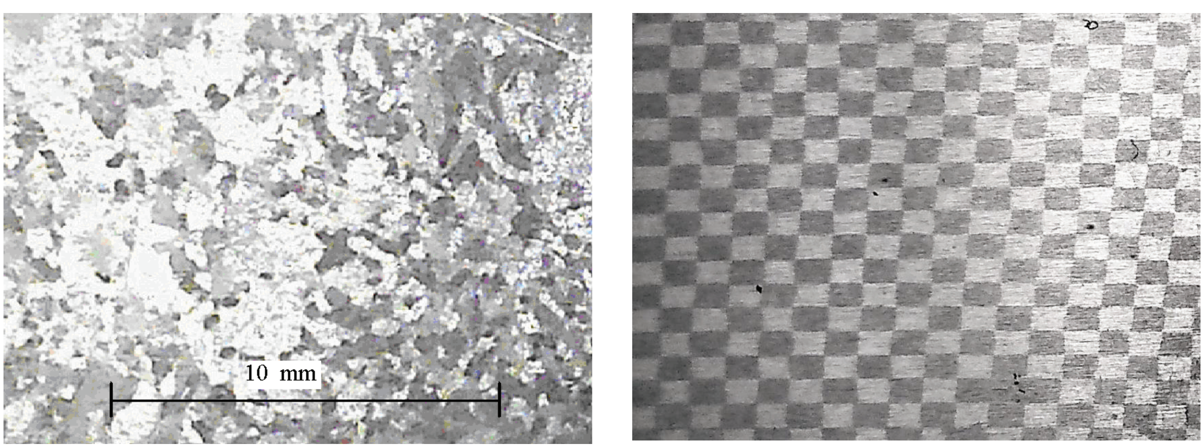
Abstract. Experimental results have determined the mesostrain characteristics of aluminum in a plane stress-strain state. Tensor components of plastic deformations are defined for grains in a plane of a rolled aluminum sheet. The intensity of principal mesostrains is calculated. The correlation between deformations of individual parts is estimated by the Z-normalized autocorrelation functions. Strain distribution laws are formulated. Parameters of stress-strained grains are indicated.

EXPERIMENTAL METHOD

The experiment is carried out using the grade grid method applied on a specimen plane surface [1–3]. Photographic grid composition is a mixture of 10 ml of a 7% PVA (polyvinyl alcohol) solution and 10 ml of a saturated ammonium dichromate solution. A thin layer of photographic composition is applied to the sample surface with a brush. The applied layer is thereafter dried by a dryer. Then, the grid exposure is performed by a precision calibration block (or reference gauge) with square cells of a chess type. The block is printed on a transparent film for inkjet printers. During the exposing process the film is pressed tightly to the sample surface using a glass plate. The photographic composition is struck by the light of a 10W LED projector. As a result of photochemical reaction, chromium ions Cr +6 are transferred into the trivalent state Cr +3 under the influence of a light quantum. At the same time, the composition which is under the transparent block areas is transferred into the insoluble state. The exposing time is 5 to 10 minutes. The areas that have not been struck by the light are removed in the subsequent washing of the sample in the running water. To increase the contrast, the grid is colored by aniline purple dye.

Grain boundaries were determined by etching in a standard acid solution (aqua regia). The etching regime was selected experimentally. The average grain size (Fig. 1a) was determined by the random linear intercept method. The size of the part of a grid cell was commensurable with the average grain size of the specimens, which was equal to 1 mm (Fig. 1b).



(a) (b)

FIGURE 1. The surface of the specimen: (a) – microstructure; (b) – grade grid after deformation, equal to 42%

Aluminum specimens of rectangular cross-section with dimensions of 40×110×4 mm were prepared in several stages. A cast specimen was made from a melt of granulated aluminum (Pure for Analysis classification, analytical reagent grade). The melt overheating temperature was 1070 K. Heating was performed in an air furnace. The melt was

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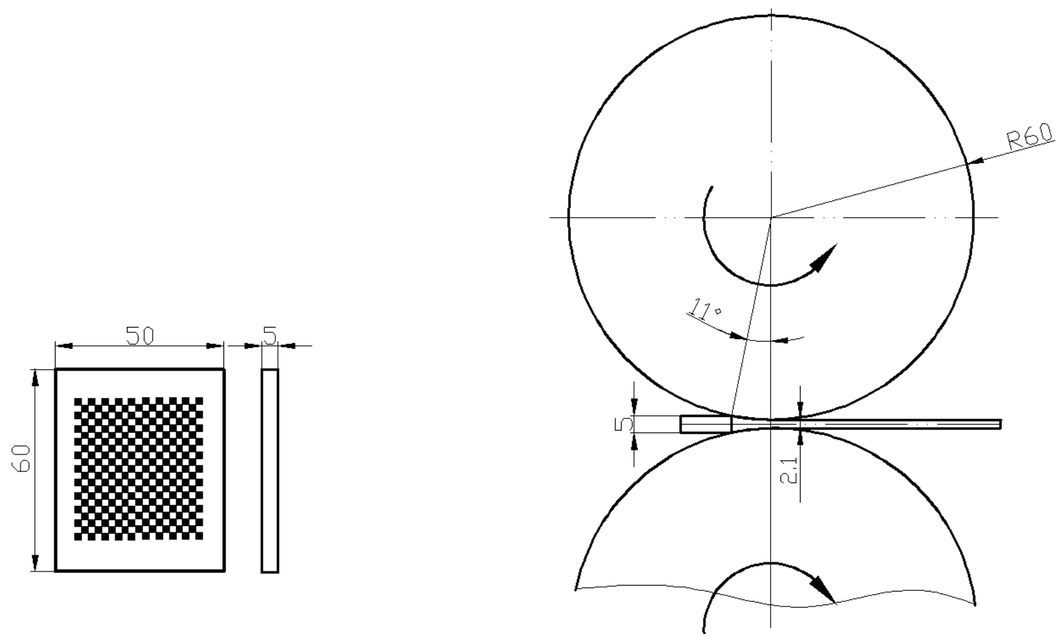
poured into a firebrick form. Thereafter, the cast was subjected to homogenizing annealing (500 K, holding time 6.5 h, furnace cooling) and then rolled on a DUO-120 mill to the amount of strain of 50%. After rolling, the cast was annealed at 1070 K for 7 minutes. The cast was cut into specimens for testing. The required evenness and flatness of the specimen surface was obtained by grinding on a cast iron lap using ACM 28/40 diamond paste.

The specimens were rolled up to various amounts of strain between 20% and 50%. This paper presents the results obtained with the amount of strain of 42% (Fig. 2b).



(a) (b)

FIGURE 2. The scheme of the experiment: a) an aluminum specimen; b) the rolling scheme

Grid unit coordinates before and after deformation were measured according to the digital photos by means of the AutoCAD system. The image scale on the monitor was chosen in such a way that the average size of a grid cell part was equal to 20 mm. The measurement results were recorded in text files for further processing with the help of an AutoLISP program [2].

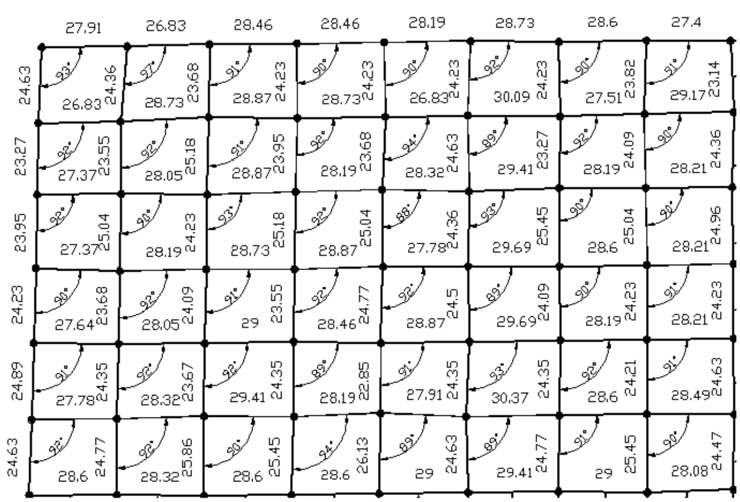


FIGURE 3. A fragment of the measurement results (side length of cells and shear angles)

The proposed measuring method of initial and deformed grade grids provides a number of stages (Fig. 3). They are as follows.

1. An image of initial and deformed grids is obtained with the help of a high resolution digital camera. In the photo process we provide a perpendicular alignment of the optical axis of the camera lens to the specimen plane, as well as a parallel alignment of the specimen planes and the display image.

2. A digital file of the raster image of the grid is opened on the main AUTOCAD screen.

3. A computer operator manually marks the nodes of the grid on the screen by grid (fixed) points. The fixed points are performed in the form of a circle. The diameter of the circle ranges from 1/10 to 1/5 of the cell size on the screen.

4. The AutoCAD program allows setting accurately the cursor in the center of each circle. During the measurement process, the following parameters are determined:

a) the coordinates of the grid cell nodes;

b) the side length of each cell;

c) the shear angle;

Grid cell deformation is calculated in the specimen plane according to measurement results: the direct axis (rolling axis direction) ε_{11}, the cross axis ε_{22} and shear ε_{12}. This helps to calculate the principal mesostrains ε_1. The strain ε_3 is calculated from the microvolume incompressibility condition,

$$\varepsilon_1 + \varepsilon_2 + \varepsilon_3 = 0. \tag{1}$$

The stress-strain state is evaluated by the random Nadai-Lode parameter

$$\chi = (2\varepsilon_2 - \varepsilon_1 - \varepsilon_3)/(\varepsilon_1 - \varepsilon_3). \tag{2}$$

The Z-coordinates of the normed correlation functions (correlation coefficient ρ) are defined according to the method discussed in [1]. In plotting the correlation, the function intervals τ and τ' are generally expressed in relative units – in whole fractions of the grid cell part (of the grain). Thus, $\tau = \tau' = 1$ for neighboring grains, and $\tau = \tau' = 2$ between the 1st and 3d grains, etc. In this case, the correlation coefficients are ρ_{12} and ρ_{13} respectively.

KEY RESULTS

The density of mesostrain distribution in the rolling direction corresponds to the normal distribution (the mean value is 0.45, the standard one is 0.09 and the variation coefficient is 21%). There is practically no grain deformation in the cross direction (the lateral distribution value is at most 1.5% to 2.0%). The mean value of shear strains is 0.028. The curves representing the density of the distribution of principal mesostrains are symmetric with respect to the origin of coordinates (Fig. 4a). A similar effect is observed in specimens of the rolled stainless austenitic steel Kh18N10T [4,5]. The distribution density of a random Nadai-Lode parameter in aluminum mesostructure for most of the metal grains corresponds to the stress-strain state of pure shear. The distribution density mode is zero. The maximum and minimum values of χ account for the magnitude from -0.38 to +0.40 (Fig. 4b) respectively.

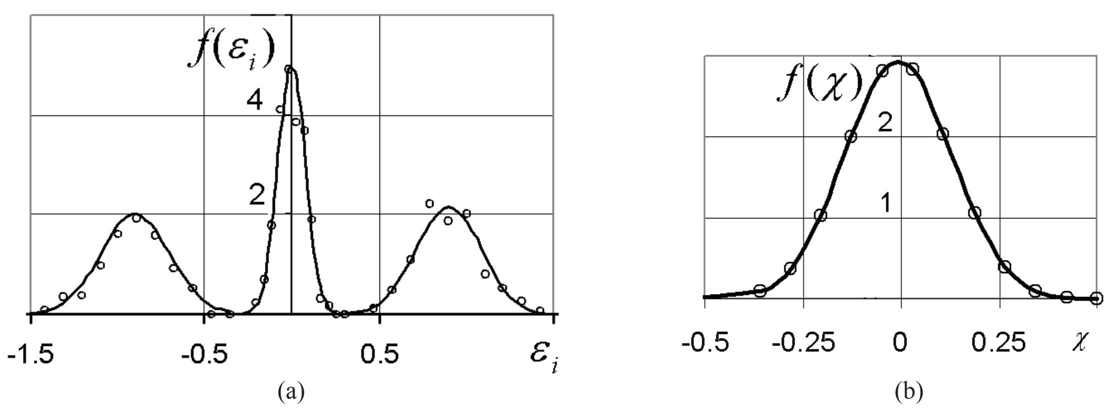


FIGURE 4. The density of mesostrain distribution: principal mesostrains (a); random Nadai-Lode parameter (b)

As seen from the diagram, the ordinates are damped along the rolling axis with the increasing distance τ between the grains. The linear relationship between mesostrains decreases in the cross direction according to the exponential law. The correlation radius comprises 2 or 3 distances τ corresponding to 2-5 mm on the specimen surface (Fig. 5).

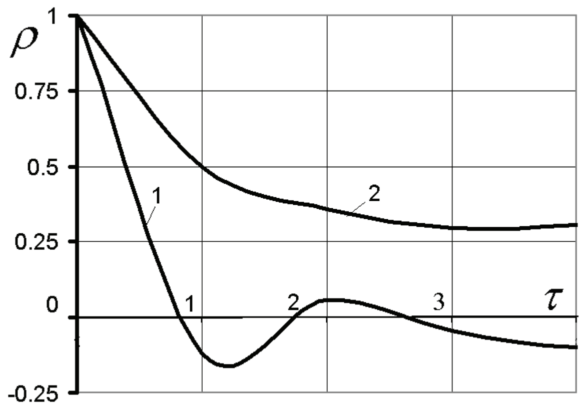


FIGURE 5. Correlation functions of aluminum mesostrains: along (1) and across (2) the rolling axis

The probabilities of the occurrence and distribution of overloads in the mesostructure are equal to the relative content of grains and neighboring grain couples in which the intensity of mesostrains exceeds the value of uniform δ_p [1]:

$$P(\varepsilon_u > \delta_p) = 1/2 - \Phi[(K-1)/J_u],$$

$$P(\varepsilon_u, \varepsilon_u' > \delta_p) = P(\varepsilon_u > \delta_p) - T\left[(K-1)/J_u, \sqrt{(1-\rho)/(1+\rho)}\right],$$

where Φ and T are the tabulated integrals of 1 and 2 points of normal probability, J_u is the variability coefficient of casual grain strain intensity, ρ is the coefficient of correlation between strain intensities in neighboring grains, $K = \delta/\varepsilon_u$ is the assurance coefficient for uniform deformation.

SUMMARY

- The experimental laws of mesostrain distribution for pure aluminum are consistent with the Gaussian distribution.
- Rolling on a DUO-120 mill results in a plane stress-strain state corresponding to pure shear, the lateral distribution value being at most 1.5–2.0%.
- The stress-strain state of specimen mesovolumes predominantly corresponds to pure shear. Only a relatively small grain proportion (20% to 30%) is subjected to behavior other than pure shear.
- The mesostrain fields are anisotropic, i.e. the sections of normed autocorrelation functions are different in orthogonal directions with respect to the rolling axis.
- The results are applicable to the estimation of the probability of strains in individual grains that 2 to 3 times exceed the strain value of the whole aluminum specimen.

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